# SOME SCIENTIFIC ASPECTS OF THE METEOROLOGICAL WORK OF THE UNITED STATES ARMY.

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(*Read April 26, 1919.*)

There is no more interesting illustration of the application of new scientific methods to warfare than is furnished by the developments in meteorology during the great war. Prior to 1914 a meteorological section was not considered a necessary part of the military service. No corrections had ever been made by the artillery of any army for any save surface winds. Firing by the map was almost unknown. No Sound-ranging Service, no Air Service and no Anti-aircraft artillery had ever existed to demand aërological data.

At the time of the signing of the armistice on the western front the Air Service and all the artillery were being furnished every two hours with the temperature, density, wind-speed and direction, taken at the surface and at various altitudes, from 100 to 500 meters apart, up to 5,000 meters. Further, tables were prepared from which each battery could obtain the correction suited to its trajectory for the so-called ballistic wind. This is, the average wind for the trajectory, weighted for the density of the air at the elevations traversed. Even machine guns when used for barrage work made use of these ballistic-wind tables.

In addition, daily forecasts were furnished to the armies in accordance with the following outline:

*A*. Character of weather for each arm of the service.

*B*. Winds: Surface at 2,000 m., at 5,000 m.

*C*. Cloudiness including fog and haze.

*D*. Height of cloud.

*E*. Visibility.

*F*. Rain and snow.

*G*. Temperature.

*H*. Warning of weather conditions favorable for use of gas by enemy.

*K*. Probable accuracy or odds in favor of forecast.

Most of the aërological data was obtained from theodolite observations on pilot balloons. The extent to which our knowledge of the upper air has been, and is being, extended by this pilot balloon work may be seen from the fact that before the war there existed but one station in the United States where pilot balloon explorations were regularly carried on. Within a year of the inception of the meteorological service in the United States Army, thirty-seven complete stations for the obtaining of both surface and upper air data in aid of aviation and the artillery had been established in the United States and equipped with special aircraft theodolites and pilot balloons, neither of which had ever been produced before in this country. Further, twenty such stations had been established by our forces abroad. For the manning of this service, about five hundred specially selected men had been trained in this country, and three hundred and fourteen of them sent abroad, while about two hundred were held for work in the United States.

The scientific interest in this service centers about four distinct problems:

1. The extension of our knowledge of the law of motion of pilot balloons.

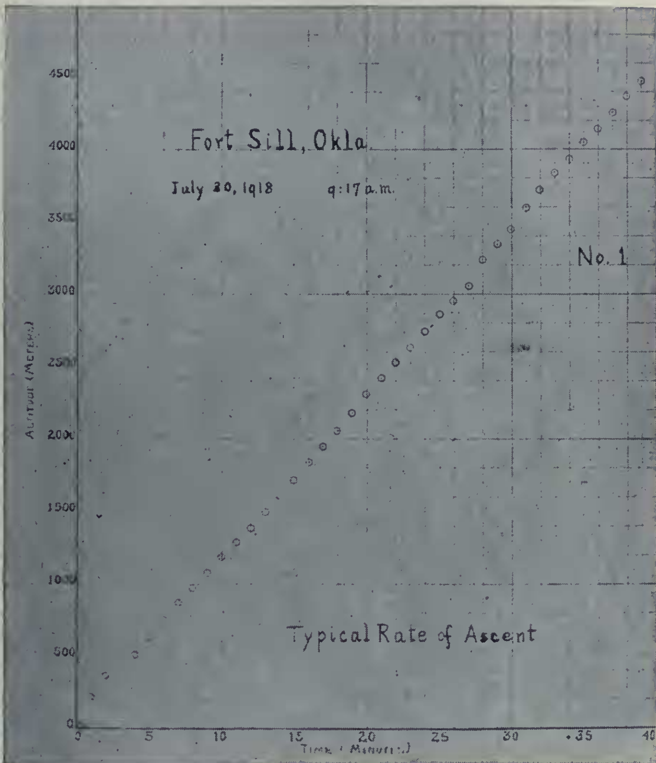
2. The procurement of data and the development of methods for the preparation of artillery range tables.

3. The development of long range propaganda balloons.

4. The charting of the upper air in the United States and overseas in aid of aviation.

1. *The Extension of Our Knowledge of the Law of Motion of Pilot Balloons.*—Prior to the development of the meteorological service of the army there had been made in the United States perhaps one hundred pilot balloon flights in which the balloons had been followed by the two-theodolite method—the only method which permits of real accuracy—and in several European countries there had been a somewhat greater number, but the data was incomplete and fragmentary.

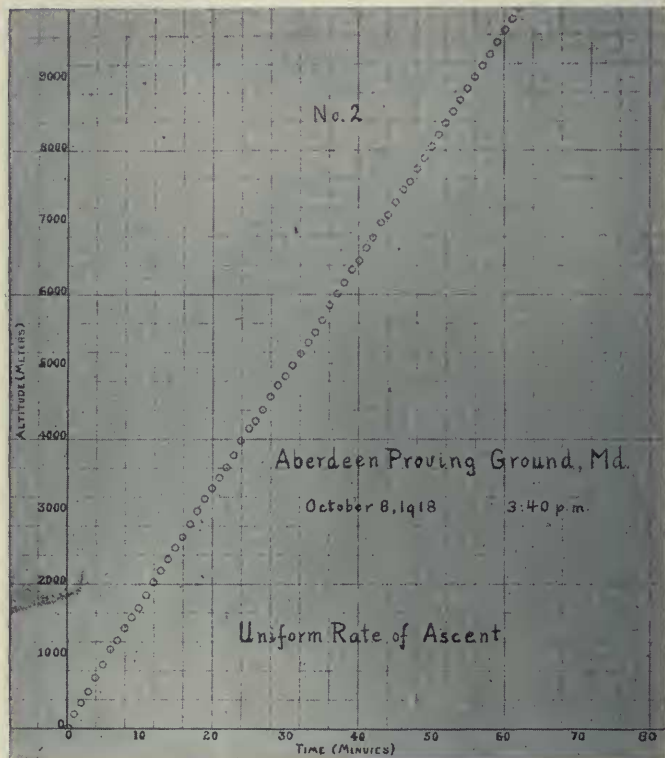
Within the past year approximately five thousand such observations have been taken by the meteorological service of the Signal Corps. From these observations the altitude of the balloon is determined with great accuracy by triangulation, the base line being usually a mile or more in length. The balloon is kept in sight up to distances as great as sixty miles, and up to heights as great as 32,000




Uniform rate of ascent of pilot balloon up to 4,500 meters.

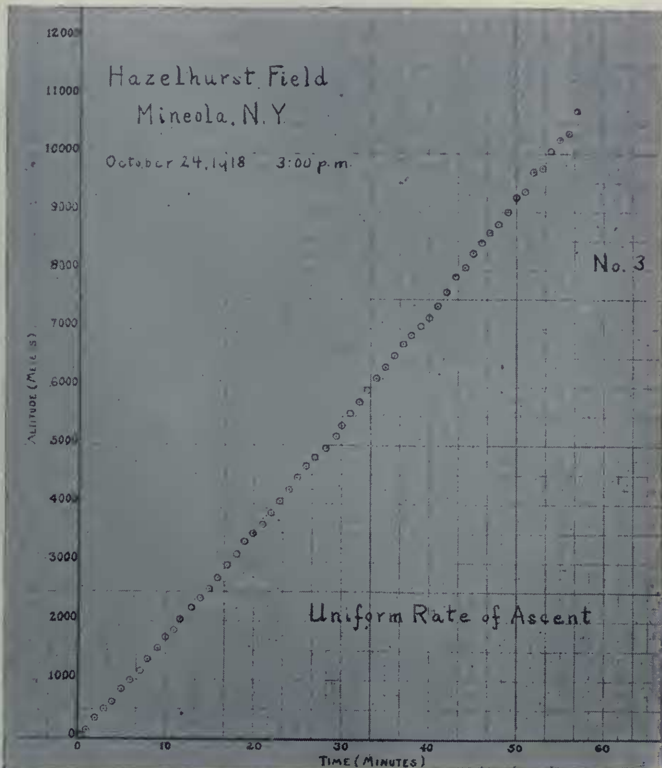
meters, or approximately twenty miles. For the practical uses of the artillery and the air service, observations need not be carried higher than 10,000 meters (six miles), which is the extreme height to which airplanes have thus far ascended, or to which projectiles usually go.

In view of the number of variables which enter into the rate of ascent of pilot balloons, such as the changing density and the changing temperature of the surrounding air, the changing size of the balloon and consequent changing tension of the rubber envelope, the changing temperature of its interior because of the absorption of the sun's rays, the diffusion of hydrogen through its walls, etc., it is one of the most striking facts to be found anywhere in the annals



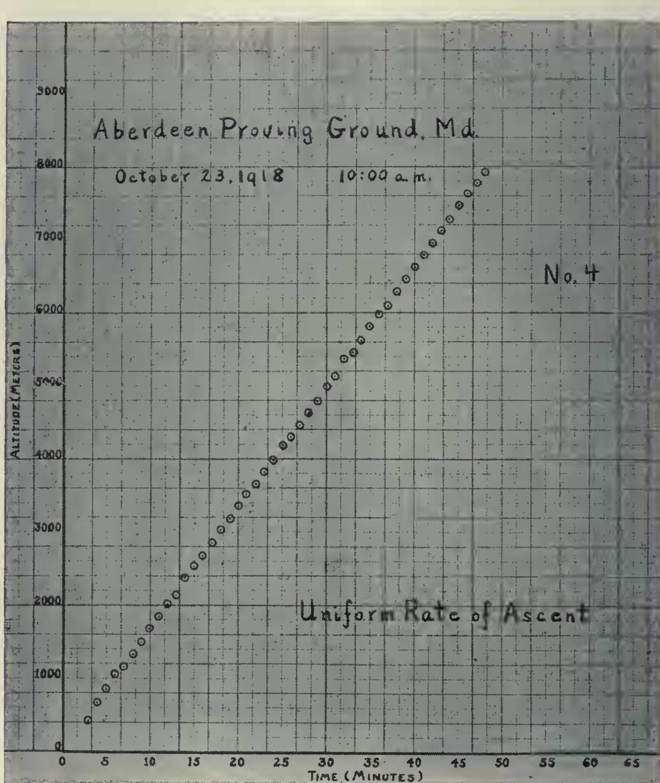

Uniform rate of ascent of pilot balloon up to 10,000 meters.

of empirical science that these balloons rise to great heights without deviating appreciably from the simplest possible law of ascent, namely, that of constant speed. Graphs Nos. 1, 2, 3, 4 and 5 show beautiful examples of this constancy. Graph No. 6 shows a kink at about 5,500 meters, which is presumably due to a descending current struck at that altitude. Graph No. 7 shows a balloon followed to a height of 20,000 meters where it apparently developed a leak and failed to ascend further. Graph No. 8 shows the fluctuations which are often found at low altitudes, these fluctuations being undoubtedly due to ascending and descending currents.




Uniform rate of ascent of pilot balloon up to 11,000 meters.

The extreme constancy in the rate of ascent, shown in a great majority of flights, although surprising enough, is not as inexplicable as it at first appears, for since the pressure within the balloon due to the tension of the rubber itself is only from five to eight centimeters of water, and since this pressure is at sea level less than 1 per cent. of the pressure of the atmosphere, it will be seen that the balloon will expand practically freely, that is, as though the walls did not constrain it at all, up to heights of say 10,000 meters where the pressure is about a third of an atmosphere. This means that the ascensional force must be entirely independent of temperature and pressure.[1] For the speeds with which these balloons ascend, namely, about three meters a second, the resistance to motion must be directly proportional to the density of the air and experiment

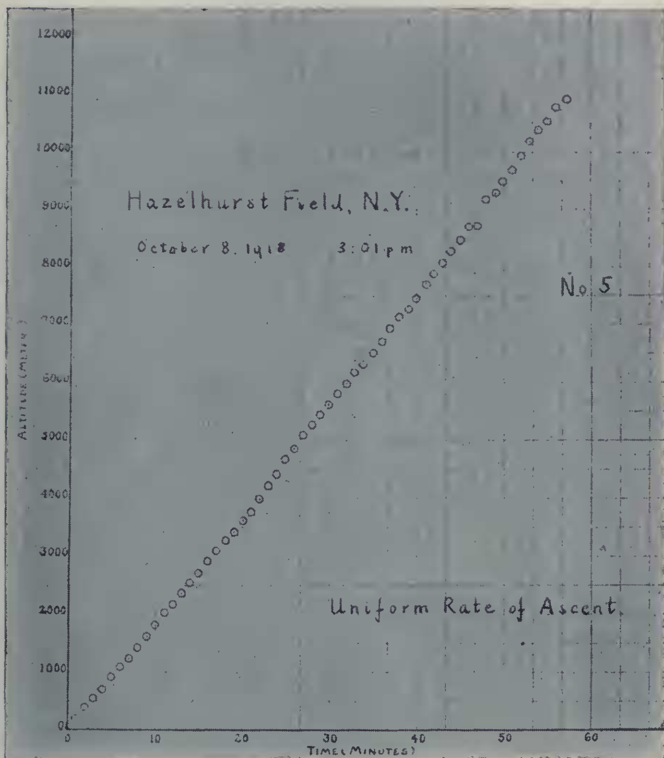



Uniform rate of ascent of pilot balloon up to 8,000 meters.

shows it to be nearly proportional to the cross section of the balloon, that is, to the square of the radius. This makes the resistance vary

[1] For if $f_1$, $d_1$, $v_1 p_1 t_1$ represent ascensional force, density, volume, pressure and temperature at the surface of the earth, and $f_2$, $d_2$, $v_2$, $p_2$, $t_2$, the corresponding quantities at any given elevation, then since $d_2/d_1 = v_1/v_2 = p_2 t_1/p_1 t_2$ (1) and $f_1/f_2 = v_1 d_1/v_2 d_2$ (2) there results from a combination of 1 and 2, $f_1/f_2 = v_2 d_1/v_2 d_2 = p_2 t_1/p_1 t_2 \times p_1 t_2/p_2 t_1 = 1$.

as the cube root of the density,[2] which means that at a height of 6,000 meters, where the density is about one half, the resistance is .83, of what it would be at the surface. If, as is approximately true for these speeds, the resistance varies as the square of the velocity,




Uniform rate of ascent of pilot balloon up to 11,000 meters.

or the velocity as the square root of the resistance, this would mean that the velocity should vary as the sixth root of the density. In

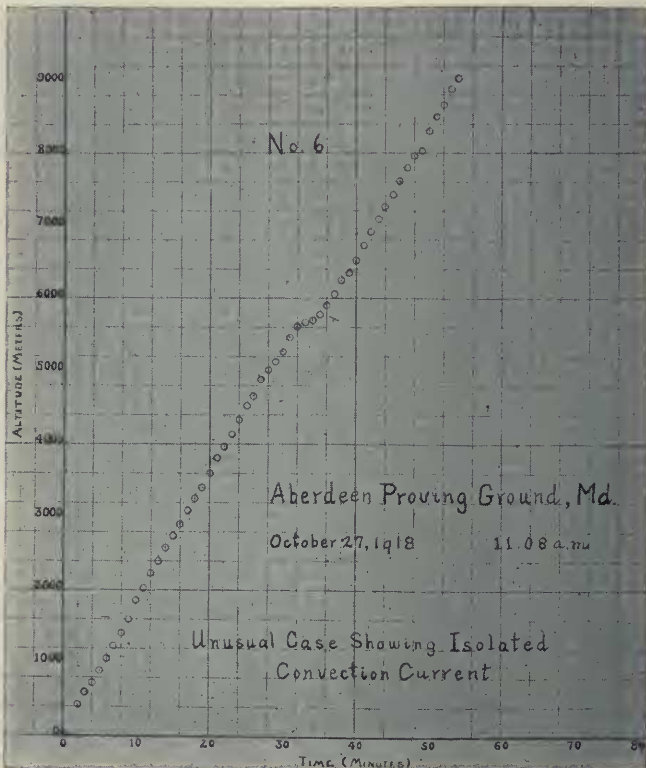
[2] For if $R_1$ is the resistance at the earth's surface and $R_2$ that at any given altitude,

$$\frac{R_1}{R_2} = \frac{V_1^{\frac{2}{3}} d_1}{V_2^{\frac{2}{3}} d_2}$$

which is seen from (1) to equal

$$\left(\frac{d_1}{d_2}\right)^{\frac{1}{3}}.$$

other words, since the sixth root of 2 is 1.13, at a height of 6,000 meters, the velocity should be about 13 per cent. greater than at the surface. Such an increase in velocity would be very easily observable in the experimental data. The fact that it is not found there

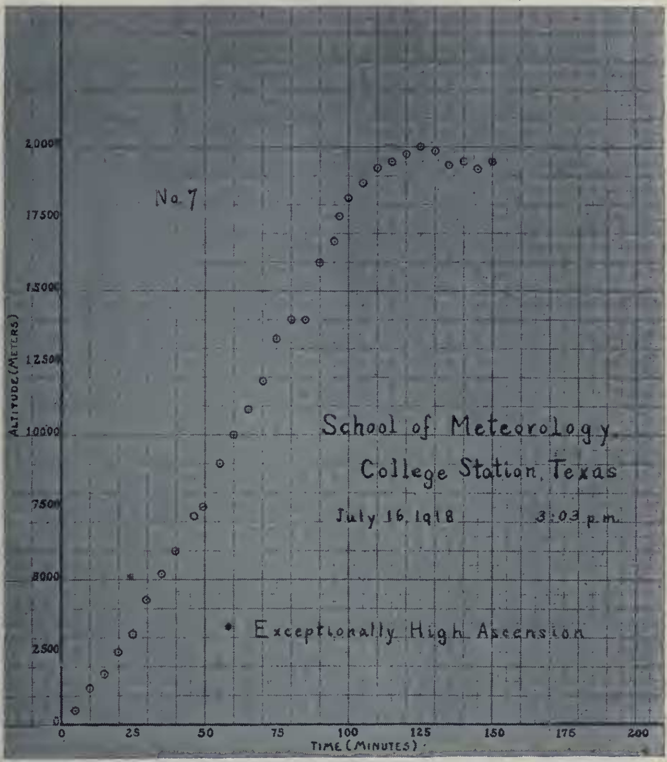



Pilot balloon ascent showing isolated convection current.

is due to the wholly fortuitous circumstance that the slow diffusion of hydrogen through the walls, as observation by Blair and Sherry has shown, is just sufficient, with the balloons here used, to retard the ascensional rate enough to make it quite exactly constant.

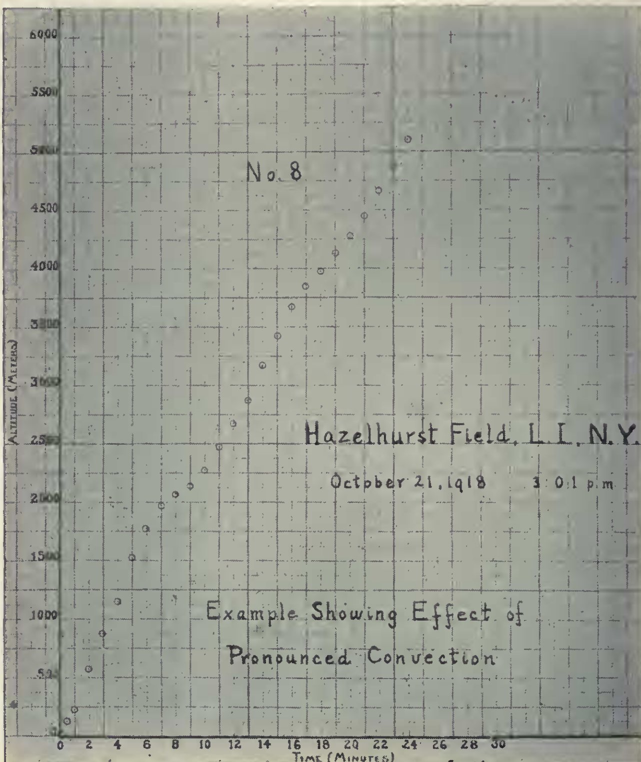
This makes it possible, provided one could always duplicate the size and weight of his balloon, to obtain a very exact determination of wind velocity and direction by a one-theodolite method, the height being always known from the time and the known rate of ascent.

When, however, the weight and inflation of the balloons are varied, as they must be in practice, since the balloons vary in weight from twenty to thirty-five grams, and since it is convenient also to vary the filling according as low altitude or high altitude wind-data




Uniform rate of ascent of pilot balloon up to 20,000 meters where balloon sprung a leak.

are desired, it is found that no accurate formula can be found for computing the speed in terms of the ascensional force, the weight to be lifted, and a single invariable constant. For approximate work, however, the one-theodolite method, because of its convenience and because of the impracticability of measuring an accurate base line at the front, is much in use, and one of the advances made in the meteorological work of the army during the past year has consisted in developing with the aid of the large amount of data available, a general formula for the rate of ascent in terms of the ascensional force and the weight to be lifted, which though far from accurate is more reliable than that which has heretofore been used. The formula heretofore used is that of Dine's, namely,




Correction currents at low altitudes.

$$V = K\frac{l^{\frac{1}{2}}}{L^{\frac{1}{3}}},$$

in which $V$ represents the rate of ascent in meters per minute, $l$ is the free lift, or the weight of the displaced air less the weight of the balloon and contained hydrogen, $L$ is the weight of the balloon plus the free lift and $K$ is a constant.

The formula as modified by the observers of the Signal Corps is

$$V = K'\left(\frac{l^3}{L^2}\right)^{.208}$$

This formula is found to fit the observational data within the ranges used in the Signal Corps work to an accuracy of somewhat less than 10 per cent., which is sufficient for most work at the front.

2. *Meteorology in the Aid of the Artillery.*—In former times when guns did not shoot to a greater distance than eight or ten miles, it was usually possible to observe where the projectile hit and to correct errors by "spotting." This made unnecessary the correction of the trajectory for the influence of the wind and the changing density of the air with increasing altitude. In the present war, however, guns have been built to shoot much farther and in addition camouflage has prevented the visual location of guns even at the old ranges. Hostile batteries have been located in many instances solely by the new art of sound-ranging which has itself demanded for the high accuracy attained aërological data. The answering battery has been obliged to fire wholly by the map, so that it is obvious that it has become necessary to make careful allowances both for the density of the air and the direction and speed of the wind at various altitudes. Some of the modern projectiles remain in the air as long as seventy seconds and a moderate wind blowing across the path of such a projectile might easily cause it to drop half a mile away from the point at which it would strike if fired in still air. The wind-direction and speed at various altitudes have been obtained, as already indicated by pilot balloons, while the temperature has been determined at the proving grounds by sending self-recording instruments aloft in specially constructed box-kites, as well as by sending self-recording instruments and meteorological observers aloft in airplanes. It has been with the aid of observations of this sort that the new range tables for the Ordnance Department of the United States Army have been constructed. The importance of this work may be understood when it is considered that these range tables will be used in connection with the firing of all guns, and errors in them would produce errors in the range of every gun fired with their aid.

3. *The Development of Long Range Propaganda Balloons.*—In view of the fact that above an altitude of 10,000 feet 95 per cent. of

the winds both over western Europe and over the United States blow from west to east (*i.e.,* have a westerly component), Captain Sherry in 1917 suggested the development of a large program for the extension of the use of pilot balloons for the purpose of flooding the whole of Germany and Austria with propaganda dropped from such balloons. The project was submitted to the meteorological and military agencies in France and pronounced infeasible, chiefly because the rapid diffusion of hydrogen through rubber had heretofore rendered it impossible to obtain pilot balloon flights of more than about 100 miles. Undiscouraged, however, by these reports, Mr. W. J. Lester, Dr. S. R. Williams and Sergeant Redman attacked the problem of extending the range of pilot balloon flights by developing an automatic ballast-control and by reducing the diffusion by means of a special dope.

The automatic control was ingeniously simple, its essential feature being a belly band which kept the girth of the balloon constant (at a diameter of four feet) through the discharge, in the act of shrinking, of a few drops of kerosene, thus causing reascension and consequent expansion.

With this device the balloon not only does not fall but rises very gradually to higher and higher levels until its ballast of kerosene or alcohol is exhausted.

In the week beginning October 3, 1918, sixty such balloons, adjusted to fly between the initial and final altitudes of 15,000 and 25,000 feet respectively were sent up from Fort Omaha, Nebraska, carrying return cards and watches, which were arranged to stop and be let down on small parachutes as soon as the ballast was exhausted. Thirty-four out of sixty of these balloons were picked up and returned to Washington. Instead of flying 100 miles, one of them came down within ten miles of New York, 1,100 miles from Fort Omaha, another was returned from Virginia, 930 miles from its starting point, and the rest were scattered over Ohio, Kentucky, Illinois, Wisconsin and Iowa. Not one went west of Omaha though the balloons were sent up on days on which different surface conditions prevailed.

The credit for this achievement, the significance of which will be discussed later, is due primarily to Mr. Lester, Captain Sherry, Dr. Williams and Sergeant Redman. At the time of the signing of the armistice the Military Intelligence Service was preparing for the extensive use of these balloons for flooding the whole of Germany, Austria and even parts of Russia with suitable leaflets, several hundred of which could have been scattered by a single balloon, the total cost of which would have been but two or three dollars.

TABLE I.

War Department, Signal Corps, U. S. Army, Meteorological Service.

Station Ellendale, N. D. (90th Meridian Time.)

*Wind Aloft Report.*

Time 7:00 A.M. Date November 13, 1918.

| Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. | Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. |
|---|---|---|---|---|---|---|---|
| 0 | SW | 29 | | 5,250 | NW | 57 | |
| 250 | S | 17 | | 5,500 | NW | 60 | |
| 500 | SW | 16 | | 5,750 | NW | 59 | |
| 750 | SW | 15 | | 6,000 | WNW | 63 | |
| 1,000 | W | 15 | | 6,250 | NW | 69 | |
| 1,250 | W | 16 | | 6,500 | NW | 68 | |
| 1,500 | WNW | 18 | | 6,750 | NW | 68 | |
| 1,750 | WNW | 19 | | 7,000 | NW | 74 | |
| 2,000 | WNW | 22 | | 7,250 | NW | 77 | |
| 2,250 | WNW | 25 | | 7,500 | NW | 85 | |
| 2,500 | WNW | 27 | | 7,750 | NW | 65 | |
| 2,750 | WNW | 34 | | 8,000 | NW | 73 | |
| 3,000 | WNW | 35 | | 8,250 | NW | 76 | |
| 3,250 | NW | 35 | | 8,500 | NW | 69 | |
| 3,500 | NW | 40 | | 8,750 | NW | 75 | |
| 3,750 | NW | 41 | | 9,000 | NW | 73 | |
| 4,000 | NW | 41 | | 9,250 | WNW | 74 | |
| 4,250 | NW | 47 | | 9,500 | WNW | 68 | |
| 4,500 | NW | 53 | | 9,750 | WNW | 65 | |
| 4,750 | NW | 56 | | 10,000 | WNW | 78 | |
| 5,000 | NW | 54 | | 10,250 | NW | 81 | |

4. *The Charting of the Upper Air in Aid of Aviation.*—In a recent Brisbane editorial the following sentence occurs: "Flying machines of the future going long distances will travel at least 32,000 feet up, where no wind blows except the gentle eastern wind caused by the earth's motion on its axis." It is quite likely that the future aviator will fly high, but his motive will be to find an air current, not to escape one. The gentleness of the zephyrs existing at high altitudes may be seen from tables 1, 2, 3, 4 and 5 which record three sets of pilot balloon observations recently taken by the Signal

Corps. These tables show air currents increasing in intensity with increasing altitude and approaching the huge speed of 100 miles per hour. Such speeds are perhaps exceptional, but not at all un-

TABLE II.

War Department, Signal Corps, U. S. Army, Meteorological Service.

Station Groesbeck, Texas. (90th Meridian Time.)

*Wind Aloft Report.*

Time 7:00 A.M. Date November 1, 1918.

| Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. | Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. |
|---|---|---|---|---|---|---|---|
| 0 | E | 9 | | 6,750 | WNW | 25 | |
| 250 | ESE | 16 | | 7,000 | WNW | 19 | |
| 500 | ESE | 13 | | 7,250 | W | 8 | |
| 750 | ESE | 2 | | 7,500 | W | 12 | |
| 1,000 | WSW | 5 | | 7,750 | W | 9 | |
| 1,250 | WNW | 11 | | 8,000 | WSW | 4 | |
| 1,500 | WNW | 18 | | 8,250 | WSW | 16 | |
| 1,750 | WNW | 23 | | 8,500 | WNW | 20 | |
| 2,000 | NW | 25 | | 8,750 | W | 22 | |
| 2,250 | NW | 20 | | 9,000 | WSW | 20 | |
| 2,500 | WNW | 20 | | 9,250 | WSW | 20 | |
| 2,750 | NW | 23 | | 9,500 | WSW | 22 | |
| 3,000 | NNW | 21 | | 9,750 | WSW | 28 | |
| 3,250 | N | 18 | | 10,000 | W | 39 | |
| 3,500 | NNW | 29 | | 10,250 | W | 47 | |
| 3,750 | NW | 25 | | 10,500 | W | 50 | |
| 4,000 | NNW | 20 | | 10,750 | WNW | 59 | |
| 4,250 | NW | 20 | | 11,000 | WNW | 57 | |
| 4,500 | NW | 21 | | 11,250 | W | 44 | |
| 4,750 | NW | 20 | | 11,500 | W | 39 | |
| 5,000 | WNW | 16 | | 11,750 | W | 41 | |
| 5,250 | WNW | 18 | | 12,000 | W | 47 | |
| 5,500 | WNW | 35 | | 12,250 | W | 51 | |
| 5,750 | WNW | 35 | | 12,500 | W | 56 | |
| 6,000 | WNW | 32 | | 12,750 | W | 59 | |
| 6,250 | WNW | 25 | | 13,000 | W | 60 | |
| 6,500 | WNW | 26 | | 13,250 | W | 64 | |

known. The pilot balloon mentioned in 3 travelled from Omaha to Virginia at an *average* speed of thirty miles per hour, the average height being 18,000 feet. On November 6, 1918, at Chattanooga, Tennessee, a velocity of 154 miles an hour at an altitude of 28,000 feet was observed by one of the meteorological units of the Signal Corps.

These facts bring out the importance of a forecast of such currents for the purposes of long flights. A flier aided by such a wind

TABLE III.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Ellendale, N. D. (90th Meridian Time.)

*Wind Aloft Report.*

Time 8:26 A.M. Date December 5, 1918.

| Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. | Altitude, Meters. | Direction, Meters. | Velocity, M. P. H. | Remarks. |
|---|---|---|---|---|---|---|---|
| 0 | NW | 19 | | 1,750 | NW | 64 | |
| 250 | NW | 47 | | 2,000 | WNW | 68 | |
| 500 | NW | 49 | | 2,250 | WNW | 81 | |
| 750 | NW | 57 | | 2,500 | WNW | 87 | |
| 1,000 | NW | 48 | | 2,750 | WNW | 96 | |
| 1,250 | WNW | 49 | | 3,000 | WNW | 93 | |
| 1,500 | WNW | 50 | | | | | |

TABLE IV.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Mineola, L. I. (75th Meridian Time.)

*Wind Aloft Report.*

Time 7:06 A.M. Date September 7, 1918.

| Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. | Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. |
|---|---|---|---|---|---|---|---|
| 0 | N | 18 | | 2,000 | SW | 25 | |
| 250 | N | 51 | | 2,250 | SW | 37 | |
| 500 | N | 65 | | 2,500 | SW | 63 | |
| 750 | N | 29 | | 2,750 | SW | 55 | |
| 1,000 | W | 22 | | 3,000 | SW | 54 | |
| 1,250 | W | 20 | | 3,250 | SW | 55 | |
| 1,500 | W | 11 | | 3,500 | SW | 81 | |
| 1,750 | WSW | 13 | | | | | |

as that last mentioned would move toward his objective 2 × 154, or 308 miles an hour more rapidly than if he were opposed by it. When it is recalled that the aviator above the clouds has no means of knowing anything about the motion of the air in which he flies, it will be seen that it is of the greatest importance to him to know the nature of the currents at different levels. Table 4 furnishes a very typical illustration of this importance.

From the above data it is evident that an aviator flying toward the west at this time and place should have flown at an altitude of 1,000 meters, while an aviator flying toward the east should have flown at an altitude of 4,000 meters or more.

TABLE V.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.
Station Fort Oglethorpe, Ga. (90th Meridian Time.)
*Wind Aloft Report.*

Time 7:39 A.M. Date November 29, 1918.

| Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. | Altitude, Meters. | Direction, Compass. | Velocity, M. P. H. | Remarks. |
|---|---|---|---|---|---|---|---|
| 0 | NW | 7 | | 1,750 | W | 36 | |
| 250 | NW | 8 | | 2,000 | W | 41 | |
| 500 | NW | 11 | | 2,250 | W | 46 | |
| 750 | WNW | 19 | | 2,500 | WSW | 47 | |
| 1,000 | W | 29 | | 2.750 | WSW | 56 | |
| 1,250 | W | 34 | | 3,000 | WSW | 76 | |
| 1,500 | W | 36 | | 3,250 | WSW | 96 | |

TABLE VI.

| Altitude In Meters. | Wind Direction. | Wind Velocity In Miles per Hour. |
|---|---|---|
| Surface | NW | 2.2 |
| 500 | E | 5.8 |
| 1,000 | E | 8.3 |
| 2,000 | NE | 5.4 |
| 3,000 | W | 5.4 |
| 4,000 | NW | 24.6 |
| 12,000 | NW | 49.2 |

In order to meet the obvious need of the aviator for a knowledge of upper air currents the Signal Corps in the summer of 1917 undertook for the first time in history a general program of mapping the upper air currents of the United States, the Atlantic and western Europe in aid of aviation and particularly with reference to trans-Atlantic flight. By the fall of 1918 twenty-six upper air stations, carefully distributed over the United States, were in full operation in place of the one station which has existed before the war. From these stations reports are telegraphed twice daily to the Weather Bureau in Washington. From the pilot balloon observations charts are constructed showing the wind speed and direction at the various levels: for instance, one chart shows the wind direction and speed near the ground, another chart shows the wind direction and speed 500 meters above the ground and additional charts show the wind direction and speed at the following levels: 1,000, 1,500, 2,000, 3,000 and 4,000 meters above the ground. The forecaster at Washington has the various charts before him showing wind and weather conditions prevailing over the United States within an hour and a half after the observations are made. From these charts he prepares the forecast of weather conditions for the various sections of the United States and at the same time prepares a statement of the wind and weather conditions at various altitudes along the various air routes for the use of aërial navigation. This service is already being used by the aërial mail service, and it is also used by the military flyers, as is evidenced by telegraphic requests received at various military meteorological stations for special reports on the weather and wind conditions when long distance flights are contemplated.

The problem of exploring the upper air currents over the Atlantic was at first thought insoluble on account of the absence of fixed bases, but the success of the Meteorological Service in developing its long-range propaganda balloons has now made possible the mapping of the upper-air highways across the Atlantic, for arrangements are being made to send up both from coastal stations and from trans-Atlantic steamers these long-range balloons designed now for from two to three thousand mile flights, and adjusted to maintain a constant altitude and to drop in western Europe their records of average winds in these heretofore unchartable regions. The importance of this work for the future of aviation needs no emphasis.

The success which the Meteorological Service has attained would have been wholly impossible had it not been for the intimate and effective coöperation which has been extended to it in all of its projects by Director Marvin and the whole staff of the United States Weather Bureau. The chief credit for the work abroad should go to Major William R. Blair, commissioned from the Weather Bureau for the observational work with the A. E. F. For the success of the service in this country Captain Sherry and Lieutenant Waterman have perhaps the chief responsibility. Captain Murphy and Professor Fassig have, however, contributed very important elements.

University of Chicago,
April, 1919.